

## **Unified Aerosol Microphysics for NWP**

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Document Number: N0001411WX21187  
<http://www.nrlmry.navy.mil/aerosol>

### **LONG-TERM GOALS**

The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles over any region of the world for timely use in planning and executing DOD operations and activities. Specifically, the goal is to develop a COAMPS that is capable of simulating the full range of interactions between aerosol particles, clouds, and radiative transfer while remaining flexible, extensible and operationally practical. The fundamental predicted variables are the concentrations of those aerosol species that are responsible for degradation of Electro-Optical (EO) propagation or that modify cloud behavior and lifetime.

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE <b>30 SEP 2011</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2011 to 00-00-2011</b>	
4. TITLE AND SUBTITLE <b>Unified Aerosol Microphysics for NWP</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Research Laboratory, 7 Grace Hopper Avenue, Monterey, CA, 93943</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>5</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## OBJECTIVES

The primary objective for this project is to design and implement a flexible and extensible mechanism into COAMPS that allows new scalar variables to be added and accessed with less effort, thus enabling new development of more complex cloud-aerosol interactions. The work on this project has been divided into two phases, an investigation phase followed by an implementation phase. Because upgrading scalar variable handling is a major change to a model's infrastructure, we decided to focus significant effort in the investigation phase to refine the requirements and evaluate a number of software designs.

Another objective is the development of an aerosol microphysics library and emission inventories for use by COAMPS and other models. The final objective is a version of COAMPS configured to forecast the major aerosol species, yet suitable for operational use. The proposed capabilities will provide numerous opportunities to study and solve problems of interest to the Navy and DOD, as well as the climate community.

## APPROACH

We are using a scaled-down version of our COAMPS model to quickly test different software approaches for the representation of scalar variables. Usually a scalar variable is processed from two perspectives; it may be treated as a generic variable such as when it processed by advection, or it may be used specifically like dust in ice nucleation. The primary difficulty in adding new scalar variables is the number of locations in the software that must be modified. Since much of this editing is for general processing, it was decided to implement a mechanism where this type of code generation could be automated. We knew that associating properties to variables would be useful to support generalized or property-driven processing so we implemented a simple registry to store meta-data about scalar variables. These properties are initialized at runtime and may be modified by a user through an ASCII file without rebuilding and/or recompiling the model's software. We wrap a looping mechanism around processing steps that automatically submits variables for processing based on properties set by the user. We tested three different approaches with an evaluation at the end of each approach before coming to a design decision for the implementation.

This new version of COAMPS will be the only operational model with data assimilation capable of studying the complex interactions between clouds, aerosol particles, radiative transfer and dynamics. A target application will be modeling the SE Asia region during the 7-SEAS Campaign scheduled for FY12. Persistent smoke AODs of 0.3, coupled with cirrus optical depths of similar magnitude are likely to have a complicated impact on visible and infrared radiative transfer and the meteorology of the region. The modifications to COAMPS will allow interactive studies of the impact of smoke from different types of fires.

For the library, we are investigating the availability of global high-resolution emissions inventories for use in COAMPS, NAVGEM, and other models. NRL hosts the world's only real-time smoke emission system (FLAMBE) as well as the only high-resolution dust source database. The development of similar high-resolution emissions inventories for anthropogenic species at global scales is problematic and will be addressed.

## WORK COMPLETED

In this, our first year, we have reviewed the current implementation and reorganized existing codebase that was developed over a long period of time in an ad-hoc fashion by different researchers. We added a meta-data registry to centrally manage scalar variable properties. It is user-modifiable at runtime via ASCII file, accessed with simple, flexible, extensible API interface. We have added property driven processing, which will automate some repetitive processing such as IO, dynamics, and grid-to-grid communications. Our investigation has allowed us to reject certain approaches that are overly complex. We decided against software that generates the code because of the expertise required to maintain and extend this approach. WRF uses this technique and it provides certain benefits like reducing the time spent testing variable existence at runtime. At NRL, our scientists are experienced in NWP programming but have little support from professional software engineers. These researchers have years of experience with our models and any new approach that requires them to relearn the model would be counterproductive. Because our models are used operationally, DOD IA requirements discourage software that generates code that may be unknown to the user. Using our test model we were able to evaluate different trade-offs inherent in this project. We decided to retain the aerosol variables in a separate module that could be incorporated into future models. This software division allows us to test property-driven processing on the aerosol variables first before migrating this technique into the main body of COAMPS.

Our analysis uncovered two major drawbacks to the previous implementation of the aerosol processing that needed to be remedied first to move forward. The previous aerosol software was never designed to support more than one aerosol species being active in a single model run. A user could have dust, sea salt or passive tracers but never more than one of these per run. Of more significance, the aerosol processing was a separate model running inside the COAMPS model. The dynamics and physics processing were usually a duplication of the standard processing in the main model. The aerosol scalars used a slightly different temporal paradigm and could not be readily used with the model's microphysics processes. It took a significant redesign to overcome this barrier. A new aerosol module has been implemented from the top down that will now support any number of new aerosol variables being active in the same model run. These variables can have their existence and processing controlled by user modified settings, stored in the scalar registry. These software changes have been tested against the previous implementation and produce the exact same numerical results. For the test we used the same domain setup as that of the operational test runs being carried out by Dan Geiszler for COAMPS-OS development. This setup consists of four nested grids over Southwest. The run was a warm start initialized at 1200 GMT on 05/21/2008 and continued for 48 hours. Every three hours we calculated the budget statistics for each of the four nests. These included the total dust emissions (kg) and total mass (kg) for each grid. We also output the mean, max, min values for the dust mass ( $\text{mg/m}^3$ ) for each grid. For both runs, all of these statistics were bit reproducible to eight decimal places.

## RESULTS

These changes have made the model more flexible while maintaining transparency for R&D users. The redesigned module streamlines the addition of new aerosol species. The implemented software infrastructure follows the Earth System Modeling Framework (ESMF) organization of initialization, run, and finalize phases plus well-defined external interfaces. This allows easier interfacing with other models and makes it easier to add or change species. The redesigned module also provides a test-bed to use new registry on aerosol scalars before integrating into COAMPS model and supports development of proposed aerosol microphysics library and emission inventory.

To date the scientific results of this effort are limited, but we are able to reproduce previous dust simulations using the new software. Software that was originally produced to support a few experiments has been replaced by more capable and robust software designed to support a much richer array of investigations. We can now begin to study more important interactions of a larger set of aerosol species. In addition, these new aerosols can be used in the existing cloud microphysics and radiative transfer to study complex interactions not previously possible. A researcher may use an ASCII file to control scalar variables, turning them on or off and adjusting their processing steps at run time. Software developers have a single interface to interrogate these properties reducing much of the tedious programming. The COAMPS model software was reorganized to simplify scalar variable referencing which will reduce some of the effort to add new scalars. Integrating the aerosol processing back into the main model processing will enable new interactions previously unavailable. The previous two aerosol variables, passive tracers and dust, are still available to the user and can be used together in a single model run. The software infrastructure to support ash, smoke, sea salt, SO<sub>2</sub>, and SO<sub>4</sub> is in place, ready for the addition of species-specific source, sink and other microphysical processes.

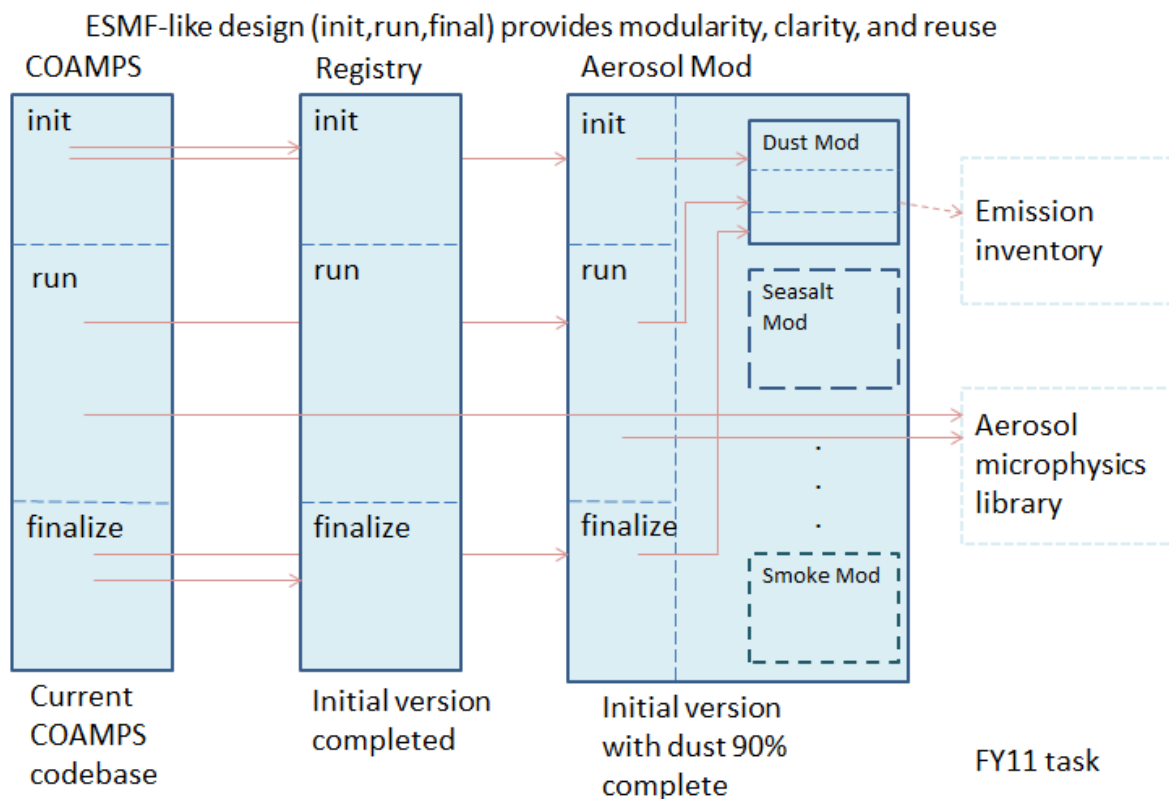
## **IMPACT/APPLICATIONS**

Climate studies have suggested the importance of interactions between aerosol particles, clouds, and radiative transfer via the processes known as the direct effect (changes in radiative transfer), semi-direct effect (changes in boundary layer dynamics), and indirect effect (changes in the cloud life cycle). Since climate is made up of many weather events, these same processes should be important to NWP. However, the case for fully interactive aerosol particles in operational NWP models has not been made. The climate metric of radiative forcing is not meaningful to NWP since extensive spatial and temporal averaging is invoked and the local impact is hidden. Regional impacts have been largely demonstrated with model sensitivity studies and anecdotal evidence. This interactive COAMPS model will allow a quantitative assessment of the significance of aerosol particles to NWP.

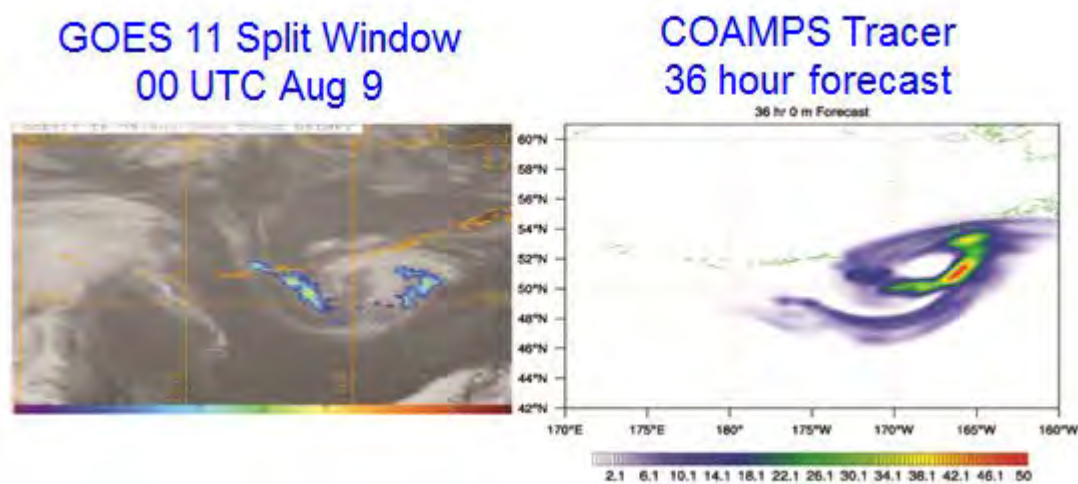
An alternate impact on NWP lies in the direct effects on remote sensing, data assimilation and validation. Aerosol particles can cause biases in satellite-sensed radiances at the top-of-the-atmosphere, errors in sea surface and other ocean and surface retrievals, and errors in forward modeling of observed quantities. An interactive COAMPS model will allow the study of these effects and the development of mitigation strategies.

## **RELATED PROJECTS**

ONR 6.2 “Application of Earth Sciences Products” supports improvements in aerosol microphysics and model initialization. The implementation of COAMPS at FNMOC is supported by 6.4 funding from PMW-120 for “Small-scale Atmospheric Models”. This funding also supports development and generation of products for use by the fleet. The NRL 6.1 Accelerated Research Initiative “Physics of Cloud Variability” helps understand atmospheric aerosol interactions. The NRL 6.2 base project “Atmospheric Correction for Oceanography” investigates the impact of aerosol particles on retrievals.



**Figure 1.** This flowchart shows the relationship between COAMPS, the new Registry and the revised aerosol module, using ESMF conventions. The sea salt and smoke sub-modules and emissions inventories are still in development.



**Figure 2.** A demonstration of the tracer capability of COAMPS. The GOES image on the left shows the retrieved distribution of volcanic ash after the eruption of the Kasatochi volcano. On the right is the 36-hour forecast from COAMPS based on a best-guess estimate of the injection scenario. The planned COAMPS model will allow rapid application of COAMPS to this and other aerosol phenomena.